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TRANSLATION

THE COMBINED USE OF PULSE ATTRIBUTES IN
PROTECTED CIRCULAR SIGNALS

By

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THE COMBINED USE OF PULSE ATTRIBUTES IN PROTECTED CIRCULAR SIGNALS

By

Yu. Tomfel'd

In the literature of late much attention has been given to code methods of constructing remote-control signals and to the combined use of pulse attributes [1, 2, 3, 4, 5], owing to the pressing need for high-capacity remote-control systems with protection against signal distortions. Some authors [5] list among the inadequacies of signals constructed by a code method the absence of circularity and the complexity of the encoding and decoding devices. It is, however, possible and advisable to transmit in one signal information concerning the state of an entire group of two-position objects, employing for this purpose relatively simple encoding and decoding circuits.

A two-position object may be in either of its two possible states. In the noncircular method of transmission each state of a particular object is transmitted by a separate signal, since it is impossible to transmit information concerning one state of the object by the presence of a particular signal and information concerning the other state by the absence of the signal. This means that for noncircular

transmission of information concerning the states of M objects it is necessary to have 2M signals. Each of these 2M signals must be placed in correspondence with one of the states of one of the objects. In order to report on the states of all M objects in the case of the noncircular method of transmission, it is necessary to send M signals one after another.

In the circular method of transmission, information concerning the states of all M objects is transmitted simultaneously in one signal. It is known that M two-position objects may yield 2^M combinations of their states. In circular transmission each of the 2^M states of the objects has its own special signal placed in correspondence with it. It follows from this that for circular transmission in groups containing M two-position objects it is necessary to have 2^M signals*. Moreover, information concerning both states of each object is transmitted, just as in the noncircular method, by an active signal and not by the absence of a signal. The number of signals per object is determined by the formula

$$N_0 = \frac{2^M}{M},$$

In Table 1 we can see how the number of signals N_0 per object depends on the method of transmission and on the number of objects in the group (M). It would seem that the circular method of transmission is not advantageous, since it requires a large number of

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* This condition is fulfilled in existing circular signaling systems. Hence we can conclude that an important criterion for the use of pulses (the number of signals per pulse) can be no less in the circular method of transmission than in code selection [7].

TABLE 1

Number of objects in group, M	1	2	3	4	5	6	7	8	9	10
Number of signals in noncircular transmission, N_0	2	2	2	2	2	2	2	2	2	2
Number of signals in circular transmission, N_{OC}	2	2	2,7	4	6,4	10,7	18,3	32	56,9	102,4

signals per object. However, we have yet to examine its advantages.

The combined use of pulse attributes, dealt with in Prof. M. A. Gavrilov's papers (e.g., [2, 3]), allows a sufficient number of signals to be obtained and permits the use of the "protective refusal" method [1].

With combined use of pulse attributes, it is possible to construct systems of signals (codes) free from distortions and containing a large number of signals N chosen in accordance with the given distortions with a small number of pulses per signal. Circular transmission of information concerning the state of a group of M objects will be possible, if we use a system of signals which meets the condition

$$N \geq 2^M \tag{1}$$

Fulfillment of this condition allows all or some of the working signals of this system to be placed in correspondence with the 2^M combinations of states of the objects of the group.

Let us consider the use of signals containing only complete combination elements for circular transmission [2]. Distortions in these signals may cause the transitions $1 \rightarrow 0$, $0 \rightarrow 1$, as well as $1 \rightarrow 1$, but only between complete combination elements, and not within them,

since in the given case the complete elements do not contain incomplete combination elements.

Let us first consider signal systems protected from one distortion $1 \rightarrow 0$ or $0 \rightarrow 1$. In constructing such systems we assign as the numbers m all the odd (or all the even) numbers included in n, where n is the total number of complete combination elements in a signal. This means that all signals containing an odd (or even) number of selecting combination elements for a given n are chosen as the working signals which enter into the system. The number of signals in such a system when m and n are odd, will be determined by the formula

$$N = \binom{n}{1} + \binom{n}{3} + \ldots + \binom{n}{m} + \ldots + \binom{n}{m}. \qquad (2)$$

Analogous expressions can be obtained for the number of signals when m and n are even.

Let us represent 2^n in the form of a Newtonian binomial:

$$2^n = (1+1)^n = \binom{n}{0} + \binom{n}{1} + \binom{n}{2} + \ldots + \binom{n}{n},$$

i.e., 2^n is equal to the sum of the binomial coefficients. It is known that in a Newtonian binomial the sum of the coefficients in odd positions equals the sum of the coefficients in even positions. Taking advantage of this property, we obtain

$$N = \binom{n}{1} + \binom{n}{3} + \ldots = \frac{2^n}{2} = 2^{n-1},$$

i.e., the number of signals in a system protected against one unit distortion, when complete combination elements are used, is equal to 2^{n-1}.

When such a signal system is used, Condition (1) acquires the form:

$$2^{n-1} > 2^M. \qquad (1a)$$

It is logical to assume that of the systems which meet this condition it is advantageous to use the system with the least number of signals. But the system having the least number of signals is a system satisfying the equality

$$2^{n-1} = 2^M. \qquad (1b)$$

Hence after taking the logarithms of both sides, we obtain

$$n = M + 1, \qquad (3)$$

i.e., for circular transmission in groups of M two-position objects with protection from one unit distortion it is necessary to have M + 1 complete combination elements for forming the signals.

Well-known to us is a coding method in which one "protective" combination element is used to maintain a prescribed oddness or evenness of the numbers m i.e., for protection from unit distortions (see, for example, Hamming's paper [6]). Such a code is called a systematic code.

TABLE 2

Objects				Signals				
Object no.	1	2	3	Number of combination element	1	2	3	4
State of objects	0	0	0	System of signals (m are odd)	0	0	0	1
	0	0	1		0	0	1	0
	0	1	0		0	1	0	0
	0	1	1		0	1	1	1
	1	0	0		1	0	0	0
	1	0	1		1	0	1	1
	1	1	0		1	1	0	1
	1	1	1		1	1	1	0

In Table 2 binary numbers are used to show how it is possible to transmit information concerning the state of three objects by means of four complete combination elements. Three elements directly transmit the state of the objects, while the fourth serves to maintain the oddness or evenness of the numbers m, i.e., to protect the signal system from unit distortions. In the table the numbers in the column for the fourth element are printed in boldface type.

Realizing the circuitry for this method of transmission presents no difficulties. In fact, the coding for the first three combination elements can be realized with the aid of the contacts of the objects included in the circuit of the pulse-attribute generating relay directly through the switch contacts. In coding the fourth combination element, it is possible to use the contacts of these same objects, since the contacts form a symmetrical circuit with even working numbers. This symmetrical circuit connected through the last switch contact will ensure the actuation of the pulse-attribute generating relay, if an even number of objects are switched in, and will thus keep the numbers m odd.

It is also possible to keep m odd by means of a pulse separator, which keeps track of the oddness or evenness of the number of units during the coding of the first three code elements and switches on the pulse-attribute generating relay to code the fourth element, if this number turns out to be even.

Decoding on the receiving end can be effected with no less simple a circuit. Selection relays, which fix the selecting attributes of each pulse of the signal, directly transmit the states of the objects. The selection relay of the last combination element can serve for protection; for this purpose a symmetrical circuit with odd working

numbers of contacts of all selection relays is included in the slave circuit. This circuit ensures reception of only working signals, i.e., signals with odd m.

Control of the evenness or oddness of m can also be effected with the aid of a pulse-separator circuit. Then there will be no need for the last selection relay.

Let us now consider systems of signals protected from several unit distortions. Let us assume that in the distortions Δ (or fewer) zeros change to units (or, conversely Δ units change to zeros), where $\Delta > 1$ (see Gavrilov's article [3]). To construct a signal system free from such distortions, the numbers m are chosen in such a way that they differ from each other by $\Delta + 1$. When complete combination elements are used, a protected signal system for $\Delta > 1$ may be constructed in a manner similar to the systematic code.

In the signal $n - \Delta$ complete combination elements can yield all the combinations, while Δ elements of the signal serve to ensure that the prescribed numbers m are obtained. If, for example, when composing the signal, b units (b selecting combination elements) are used up in the $n - \Delta$ combination elements of the signal, then the Δ "protective" elements of the signal must contain $r = m-b$ units. These latter may be arranged in any combination of Δ taken r at a time. Taking all combinations of $n - \Delta$ combination elements b at a time and adding to them all combinations of Δ taken r at a time, we obtain for given b and given m the following number of signals: $\binom{n-\Delta}{b}\binom{\Delta}{m-b}$. Adding up all these numbers of signals for all possible b and all given m, we obtain a formula for calculating the number of signals in a system protected from distortions when $\Delta > 1$ for complete combination elements:

$$N_\Delta = \sum_m \sum_{b=0}^{n-\Delta} \binom{n-\Delta}{b} \binom{\Delta}{m-b}. \tag{4}$$

When using this system of signals with protection from several unit distortions for circular transmission in groups of M objects, it is possible to use those (n-Δ) complete combination elements which yield all the combinations for direct transmission of the states of the objects. In so doing, the equality

$$M = n - \Delta, \tag{5}$$

must be observed. Hence the number of combination elements in the signal

$$n = M + \Delta. \tag{5a}$$

Let us now show that Condition (1) is fulfilled in this case. In Eq. (4) let us use m_b to denote that one of the given numbers $\underline{m}$ for which the following relationship is observed for given $\underline{b}$:

$$0 < m_b - b < \Delta. \tag{6}$$

Let us write Eq. (4) in expanded form:

$$\begin{aligned} N_\Delta = \binom{n-\Delta}{0}\binom{\Delta}{m_0} + \binom{n-\Delta}{0}\left[\binom{\Delta}{m_0+\Delta+1} + \binom{\Delta}{m_0+2\Delta+2} + \ldots\right] + \\ + \ldots + \binom{n-\Delta}{b}\left[\ldots + \binom{\Delta}{m_b-2\Delta-2-b} + \binom{\Delta}{m_b-\Delta-1-b}\right] + \\ + \binom{n-\Delta}{b}\binom{\Delta}{m_b-b} + \binom{n-\Delta}{b}\left[\binom{\Delta}{m_b+\Delta+1-b} + \binom{\Delta}{m_b+2\Delta+2-b} + \ldots\right] + \ldots \end{aligned} \tag{4a}$$

In this expression all the square brackets prove equal to zero, since in parentheses of the form

$$\binom{\Delta}{m_b - \Delta - 1 - b}, \binom{\Delta}{m_b - 2\Delta - 2 - b}, \ldots$$

the expressions underneath are negative, while in parentheses of the form

$$\binom{\Delta}{m_b+\Delta-1-b}, \binom{\Delta}{m_b+2\Delta+2-b}, \ldots$$

the lower expressions are greater than the upper, on the basis of Eq. (6). As a result, only terms of the form $\binom{n-\Delta}{b}\binom{\Delta}{m_b-b}$ remain in Eq. (4):

$$N'_\Delta = \binom{n-\Delta}{0}\binom{\Delta}{m_0} + \binom{n-\Delta}{1}\binom{\Delta}{m_1-1} + \cdots + \binom{n-\Delta}{b}\binom{\Delta}{m_b-b} + \cdots \quad (4)$$

In this expression, all the cofactors $\binom{\Delta}{m_b-b}$ are positive, and some of them are greater than unity. Since

$$2^{n-\Delta} = \binom{n-\Delta}{0} + \binom{n-\Delta}{1} + \cdots + \binom{n-\Delta}{b} + \cdots,$$

it is possible to write the following equality:

$$N_\Delta > 2^{n-\Delta}$$

or, making use of Eq. (5):

$$N > 2^M,$$

i.e., Condition (1) has been observed.

In circular transmission $N_{\Delta c} = 2^M$ signals are used. Some of the N_Δ signals are not used, since the combination possibilities of the "protective" combination elements are not used. In circular transmission it makes no difference for the transmission of information concerning the states of the objects at which of the Δ positions the "protective" units, added into the signal in the amount $m_b - b$, are placed. Therefore, in obtaining $N_{\Delta c}$ from N_Δ, we discard all signals obtained from possible combinations of Δ taken $m_b - b$ at a time, except for one out of every b.

Listed in Table 3 are the values of the 2^M signals which may be used for circular transmission of the states of four objects with protection from $\Delta = 2$ distortions.

TABLE 3

Objects					Signals						
Object no.	1	2	3	4	Number of combination element	1	2	3	4	5	6
State of objects	0	0	0	0	System of signals with protection from distortion $\Delta = 2$ (numbers 1 and 4 chosen for m)	0	0	0	0	1	0
	0	0	0	1		0	0	0	1	0	0
	0	0	1	0		0	0	1	0	0	0
	0	0	1	1		0	0	1	1	1	1
	0	1	0	0		0	1	0	0	0	0
	0	1	0	1		0	1	0	1	1	1
	0	1	1	0		0	1	1	0	1	1
	0	1	1	1		0	1	1	1	1	0
	1	0	0	0		1	0	0	0	0	0
	1	0	0	1		1	0	0	1	1	1
	1	0	1	0		1	0	1	0	1	1
	1	0	1	1		1	0	1	1	1	0
	1	1	0	0		1	1	0	0	1	1
	1	1	0	1		1	1	0	1	1	0
	1	1	1	0		1	1	1	0	1	0
	1	1	1	1		1	1	1	1	0	0

Let us now consider the case where distortions cause a 1 — 1 transition between complete combination elements.

For protection from such distortions the elements in the signal are divided into groups within which there is no such transition. Any of these groups individually may serve for circular transmission of information concerning the state of $M_i = n_i - \Delta_i$ objects by the same method as in the case of $1 \rightarrow 0$ and $0 \rightarrow 1$ transitions. Here *i* is the number of the group of signal elements; n_i is the number of elements in the i-th group.

If the combination elements in the signal are divided into l groups, then the total number of circularly signalable objects

$$M = M_1 + M_2 + \ldots + M_l = \sum_{i=1}^{l} (n_i - \Delta_i). \qquad (7)$$

In the special case where there are unit distortions within the groups ($\Delta_i = 1$):

$$M = \sum_{i=1}^{l} (n_i - 1) = \left(\sum_{i=1}^{l} n_i\right) - l. \qquad (7a)$$

If, moreover, each group contains the same number n_{gr} of combination elements, then the number of objects

$$M = l(n_{gr} - 1). \qquad (7b)$$

As an example, let us consider signals consisting of three pulses of alternating polarity, in which an elongation of the pulse and an appearance of a pause after the pulse are used as the selecting pulse attributes. Such a simple example has been taken for the purpose of reducing the cumbersomeness of the table of signals.

Assuming that an elongated pulse may be shortened with the appearance of a pause, which means a signal distortion with a $1 \rightarrow 1$ transition between complete combination elements, we shall divide the combination elements into two groups. In one group will be the pauses, in the other the elongated pulses: $l = 2$; $n_1 = n_2 = 3$. According to Formula (7a),

$$M = n_1 + n_2 - l = 3 + 3 - 2 = 4,$$

i.e., with the aid of three pulses with two selecting pulse attributes we can service four objects with circular signals. If, however, we use a sufficient number of pulse attributes, then the number of pulses in a signal will be considerably less than the number of objects

serviced. Therefore the circular method of transmission is more advantageous when a combined use is made of pulse attributes than when one selecting pulse attribute is used (in the latter case $M + \Delta$ pulses are required).

Depicted with the aid of binary numbers in Table 4 is a system of three-pulse signals, which makes it possible to realize circular transmission in groups of four objects. Four of the combination elements in the signal serve to transmit information concerning the state of the objects; the other two perform the protective functions.

The circuit which realizes the method of circular transmission just examined is shown in Fig. 1.

The following notations have been adopted in the circuit diagram: T — line relays (polarized): receiving the signal transmitted through the communication line; T and T_1 — three-position relays; T_2 — neutral adjustment relay, its armature may remain attracted to either one side or the other, when the coil is de-energized; G — pulse generator relays, these relays generate alternating-polarity pulses of normal length and elongated pulses; L — relays which elongate the pulses produced by the generator (subscripts refer to the numbers of the elongated pulses); P — relays creating a pause in the communication line (subscripts designate the numbers of the pulses followed by a pause); X_1 X_2, X_3 ... — switch relays; DL — relays serving to detect the elongation of a pulse (subscripts designate the numbers of the elongated pulses); DP — relays detecting a pause after a pulse (subscripts refer to the number of a pulse followed by a pause); C, C_1, C_2, ... — signal relays; PR, PPR — auxiliary relays which switch the circuit at the receiving end on, so that it can receive; O — object contacts; CS — starting contacts.

The circuit achieves circular transmission of information concerning the states of four objects by using the signal system given in Table 4.

Keeping the numbers **m** odd and monitoring them is accomplished with the aid of symmetrical circuits made up of the object contacts on the transmitting end and the contacts of the signal relays on the receiving end. Protection against a change in the number of pulses in the signal is afforded by the last two relays of the switch on the receiving end: X_3 and X_4, the contacts of which are included in the circuit of the cutoff winding of signal relay C.

As is apparent from Fig. 1, the layout of a circuit which achieves circular transmission by using a system of signals with "protective refusal" can be rather simple. A sampling of objects differing only slightly from ordinary distributional sampling* is possible in the circuit.

It is known that the circular method of transmission is advantageous because of the decrease in the number of "beginning" relays, which serve to start the indicating transmission when a change occurs in the state of an object. In the circular method of transmission it is only necessary to have one such relay at the transmitting end per group of M objects. In the noncircular method of transmission it is necessary to have a "beginning" relay for each signalable object. Moreover, the circular method of transmission coupled with the combined use of pulse attributes can provide a material gain in the time for transmit-

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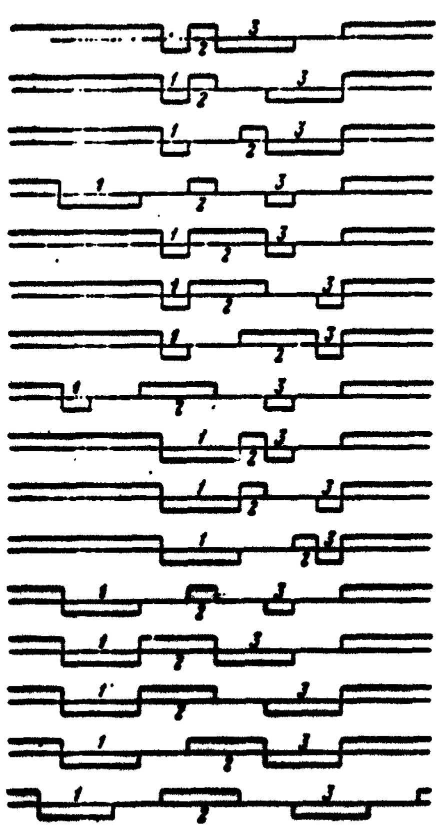
* Therefore those authors who say that the "protective refusal" method is applicable only to combination sampling (e.g., Abdullayev [4]) cannot be considered completely correct.

ting information concerning the states of the M objects.

TABLE 4

Pulse attributes		Elongation of pulse			Pause after pulse		
Groups of complete combination elements			1			2	
Pulses transmitting the states of the objects		1	2		1	2	
"Protective pulse"				3			3
Signals		1*	2*	3*	4*	5*	6*
1		0	0	1	0	0	1
2		0	0	1	0	1	0
3		0	0	1	1	0	0
4		0	0	1	1	1	1
5		0	1	0	0	0	1
6		0	1	0	0	1	0
7		0	1	0	1	0	0
8		0	1	0	1	1	1
9		1	0	0	0	0	1
10		1	0	0	0	1	0
11		1	0	0	1	0	0
12		1	0	0	1	1	1
13		1	1	1	0	0	1
14		1	1	1	0	1	0
15		1	1	1	1	0	0
16		1	1	1	1	1	1

* Complete combination elements

Presented in Table 5 is an example of the calculation necessary for circular and noncircular transmissions of a number of complete combination elements in the presence of unit distortions ($1 \rightarrow 0$, $0 \rightarrow 1$). The signals are formed by sequences of alternating-polarity pulses and are constructed as shown in Table 2. The elongation of a pulse

and the appearance of a pause after it are used as the complete combination elements, since time attributes are the most generally useful in communication channels.

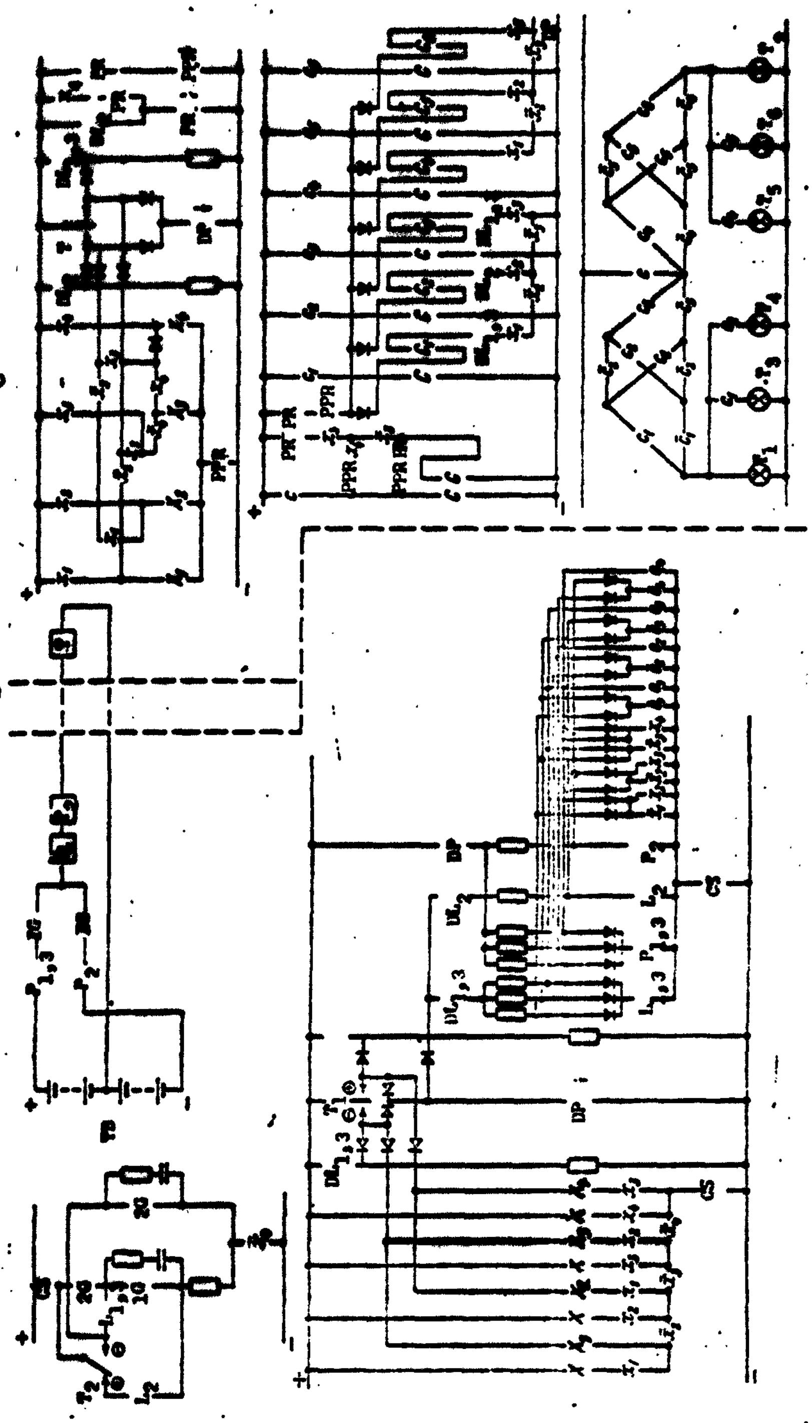


Fig. 1. Circular Transmission Circuit:
a) transmitting end; b) communication line; c) receiving end.

All the odd numbers included in n are taken as the numbers m. The limits within which lies the time necessary for circular and noncircular cyclical transmission of the state of M objects are calculated. The upper limits are calculated as the duration of a circular signal with the maximum number of objects switched in and as the sum of the durations of M noncircular signals with maximum m.

The lower limits are calculated for no objects switched in and for minimum m. In so doing absolutely no allowance was made for the time necessary to separate the noncircular signals. The duration of a pulse is taken equal to 50 msec, the duration of an elongated pulse is 150 msec, and the duration of a pause is 100 msec.

TABLE 5

Transmission	Number of objects M		2	3	4	5	8	9	16	17	32
Circular	$n_c = M + 1$		3	4	5	6	9	10	17	18	33
	$N_c = 2^M$		4	8	16	32	256	512	65536	2^{16}	2^{32}
	t_c msec	max.	400	400	650	650	1150	1150	2150	2150	4150
		min.	200	200	250	250	350	350	550	850	950
Noncircular	n_n		3	4	4	5	5	6	6	7	7
	$N_n = 2M$		4	6	8	10	16	18	32	34	64
	t_n msec	max.	800	1200	1600	3250	5200	5850	10400	15300	28800
		min.	400	600	800	1250	2000	2250	4000	5100	9600
$t_{n,min} - t_{c,max}$			0	200	150	600	860	1100	1850	2950	5450

The data in Table 5 are presented in graph form in Fig. 2. It is apparent from the graph that the difference in transmission time for the circular and noncircular methods comes out greater, the greater the number of objects in the group M.

Circular transmission can be carried out not only by using a signal system with protective refusal, but also by using systematic error correction codes (see, for example, Hamming's code [6]):

the elements of a signal carrying useful information can directly transmit the state of a group of objects.

Having examined some of the possible ways of realizing circular transmission with combined use of pulse attributes, we should also stop to consider the methods of group sampling, since in practice it is usually necessary to transmit the states of several groups of two-position objects.

There are two basic methods of group sampling:

1) the method in which a part of the elements of the signal located at its beginning is singled out especially for sampling the group [7];

2) the more advantageous skimming method in which the group is sampled by the first sampling pulse attribute in a signal, while the remaining attributes serve for sampling the objects in the group [1].

As applied to the combined use of pulse attributes in protected circular signals, these methods will appear as follows.

1. Part of the combination elements of the signal n_{gr} are singled out for sampling the group. These elements can be distributed throughout the signal in any fashion. For group sampling, of course, we can single out only those elements which carry useful information, and not the protective ones. It is more advantageous to locate the

group sampling elements at the beginning of a signal formed by a sequence of pulses, because with this location it is possible to exclude unsampled groups during the time in which the objects are sampled, and this improves the protection from interference in the communication line.

The group may be sampled:

a) by one of the elements in n_{gr};
b) by certain combinations of n_{gr}; or
c) by all the combinations of n_{gr}.

2. Skimming method. The combination elements of the group are numbered, and a sequence is made of the numbers. The combination elements present in a given signal are called selecting elements. In their positions are units in a binary number representing the signal. One or a number of the first selecting combination elements sample the group, while the rest serve to sample the objects and to perform the protective functions.

We have been considering above circular transmission using only complete combination elements in the signal. If we use incomplete combination elements, then with a small number of pulses we can obtain an even greater number of signals than when using only complete combination elements alone. The number of signals in such a system is not equal to 2^{n-1} [1, 2]. Therefore, when the system is applied to two-position objects, other methods of coding the states of a group of objects are needed.

Let us see in what way incomplete combination elements can replace complete elements, in particular, during transmission of information concerning the state of two-position objects. It is known [3] that the number of signals that can be obtained from z incomplete combination

elements is equal to $z + 1$ (included here is the null combination of the elements), whereas n complete combination elements yield 2^n combinations (Table 6). The condition for replacing complete by incomplete combination elements is expressed by the formula

$$2^n = z + 1. \qquad (8)$$

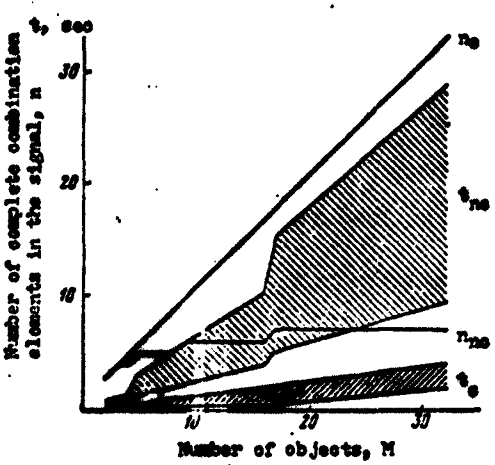


Fig. 2. Time required for transmitting information concerning the state of M objects and the number of signal elements in the circular and noncircular methods of transmission.

Hence we can easily determine the number z for given n:

$$z = 2^n - 1 \qquad (9)$$

and, conversely, the number n for given z:

$$n = [\log_2 (z + 1)],$$

where the square brackets mean that only the integral part of the logarithm is taken.

To replace incomplete combination elements by complete elements, it is necessary to take

$$n = [\log_2 (z + 1)] + 1$$

complete combination elements.

In order to transmit information concerning the state of M_1 objects, we must use as many incomplete elements as are obtained when n is replaced by M_1 in Eq. (9):

TABLE 6

	Incomplete combination elements ($z = 3$)			Complete combination elements ($n = 2$)		
	1	2	3	1	2	
$z+1$	0	0	0	0	0	2^n
	0	0	1	0	1	
	0	1	0	1	0	
	1	0	0	1	1	

$$z = 2^{M_1} - 1.$$

If there are _n_ complete combination elements, each of which contains _z_ incomplete elements, then it is possible to transmit circularly information concerning the state of

$$M = n\{[\log_2(z+1)] + 1\}$$

two-position objects.

Incomplete combination elements are convenient to use for circular transmission of information concerning the state of multiposition objects. If, for example, we compare the position of a three-position object with a table of binary numbers for two incomplete combination elements (as shown in Table 7), we can conclude that for transmission of information concerning the state of a q-position object it is necessary to have q-1 incomplete combination elements. For circular transmission of M q-position objects at a time, it is necessary to have M complete combination elements, each of which contains q-1 incomplete combination elements. This case is more general by comparison with the case of two-position objects. The method of protection from distortions and the method for constructing a protected system of signals by using incomplete combination elements has been set forth in detail by Gavrilov [2]. It is possible to show that, although in the presence of nonunit distortions it is not possible to use for circular transmission the entire system of signals set up when using incomplete combination elements, the circular method of transmission is nevertheless advantageous, owing to its simple circuitry and its speed in transmitting information concerning the state of all the objects of a group.

TABLE 7

Object				Signals		
Object No.	1			Number of complete combination element	1	
Position No.	1	2	3	Number of incomplete combination element	1	2
State of object	1	0	0	Signals	0	0
	0	1	0		1	0
	0	0	1		0	1

The state of a q-position object may also be coded with the aid of q incomplete combination elements (Table 8). A redundance (when q = 3) is exhibited through the fact that incomplete combination elements may yield one spurious position, i.e., the absence of selecting elements. This position may be utilized to detect a failure of the signal to pass from the decoder to the signal circuits, i.e., to improve the protective properties of the signal system.

TABLE 8

Object				Signals			
Object No.	1			Number of complete combination element	1		
Position No.	1	2	3	Number of incomplete combination element	1	2	3
State of object	1	0	0	Signals	1	0	0
	0	1	0		0	1	0
	0	0	1		0	0	1
				Spurious position	0	0	0

Let us consider this method, taking two-position objects with protection from unit distortions as an example. For n objects we use n complete combination elements, each of which contains two incomplete combination elements.

Each object has its own complete combination element, and each state of an object has its own incomplete combination element. The total number of units in the signal is controlled and is equal to n (Table 9). Such a signal system is protected from the unit distortions $0 \to 1$ and $1 \to 0$.

In Goryainov and Raynes' article [7] the method of signaling the states of two-position objects is called "two-position signaling." and is thus a special case of the method for q-position objects considered here. By analogy, this method of signaling the states of multi-position objects could be called "q-position signaling."

It is also possible to use the method of constructing protective signal systems set forth in Ulrich's article [8] for circular transmission of information concerning the state of q-position objects.

TABLE 9

Complete combination elements	1		2	
Incomplete combination elements	1	2	1	2
Signals	0 0 1 1	1 1 0 0	0 1 0 1	1 0 1 0
Object	1		2	
State of object	On	Off	On	Off

$n = 2;\ M = 2;\ m = 2.$

Briefly, it consists of the following. To transmit information concerning the state of M q-position objects we use signals which contain $n = M + 1$ complete combination elements. M serve to transmit useful information, and one performs the protective functions. Each complete combination element contains $z = q$ incomplete elements. The incomplete combination elements are numbered in natural sequence, beginning with one. The numbers of the selecting combination elements in that part of the signal which carries the useful information

are added up. For protection, an incomplete combination element whose number, when added to the aforesaid sum, yields a multiple of $\underline{z}$ is placed in the protective position. The sum of the numbers of all selecting combination elements in the signal is checked at the receiving end. If it is not a multiple of $\underline{z}$, the signal is distorted and protective refusal occurs.

The method just put forth allows us to achieve protection from distortions for which $1 \leq \Delta < z$.

This method is also applicable to circular transmission of information concerning the state of objects with a smooth change of state, i.e., for $q = \infty$. In this case the combination elements are placed in correspondence with all real positive numbers from zero to a certain whole-number maximum. The numbers corresponding to the selecting combination elements are added up. The sum should be a multiple of the maximum possible correlated number. The protective combination element is chosen in such a way as to fulfill this condition.

It is possible to transmit circularly information concerning the state of M_1 q-position objects by using $\underline{z}$ incomplete combination elements completely. For this purpose it is necessary that the equality

$$z = q^{M_1}. \qquad (10)$$

be fulfilled.

Conclusions

1. To transmit information concerning the state of M two-position objects in one signal (i.e., for circular transmission in a group), it is necessary to have 2^M signals, each of which corresponds to one of the combinations of states of the objects of the group.

2. The combined use of pulse attributes is more advantageous than the use of one pulse attribute for circular transmission.

3. Circular transmission may be accomplished with the aid of systematic codes by using a sampling method close to distributional.

4. In the circular method of transmission, protection from distortions may be realized both by the method of "protective refusal" and through error correction.

5. In the case of two-position objects it is convenient to use signals made up of only complete combination elements. In the case of multiposition objects it is convenient to use incomplete combination elements.

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